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PARTICLE DISCRIMINATION IN SPACE

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ABSTRACT

A number of solid state particle detectors were procured and experimentally compared. Lithium ion drift detectors were studied with respect to ability to discriminate electrons of various energies. Variation of bias current with respect to temperature was measured over the range to be expected in space vehicle applications, and degradation was measured at high temperatures. Radiation damage studies were carried out, using 1 Mev electrons and 90 Mev protons. This work was presented at the 1962 winter meeting of the American Nuclear Society.

Commerical pulse amplifiers were procured and tested in conjunction with the commercial detectors. Low noise transistorized preamplifiers were constructed, which showed lower noise characteristics than a transistorized model obtained commercially. This work has resulted in successful construction and test of a particle discriminating telescope able to detect minimum ionizing electrons above noise using a silicon detector only 0.1 gm/cm^2 thick, which is capable of measuring spectra of high energy electrons such as present in the artificial electron belts. Further studies were made of a preamplifier utilizing field effect transistors.

A nuclear emulsion experiment was prepared which did not succeed due to vehicle difficulties. Mica was exposed to nitrogen nuclei with energies between 0.1 Mev and 1.0 Mev to determine the properties of this material as a particle detector.

In connection with another program, characterization of contoured semiconductor detectors was begun. Greater stability and fairly low noise was obtained. Internal multiplication of particle pulses was obtained, although the mechanism is very uncertain.

I. INTRODUCTION

Our present knowledge of the Van Allen and artificial radiation belts is based to a large extent on the count rate data obtained from geiger tubes and ionization chambers. While these devices have gathered much valuable information, the type of data needed to increase our understanding of the nature and stability of the various belts is beyond the intrinsic capabilities of these devices.

The rapid growth of semiconductor detector technology over the last two years has provided us with devices which in principle overcome many of the limitations of the geiger tubes and ionization chambers. The most important advantages are:

1) The semiconductor detectors are capable of performing at much higher counting rates without saturating than the geiger tubes or ionization chambers.
2) Semiconductor detectors can be used to distinguish particles having different specific ionizations; this fact can be exploited to distinguish particles of different velocities.
3) Semiconductor detectors are much smaller and lighter in weight than geiger tubes or ionization chambers. Some semiconductor detectors can operate at much lower voltages than these other devices.

The major uncertainties involved in the use of semiconductor detectors are their sensitivity to radiation damage, their stability over extended periods of time and at high temperatures, and the degree to which their particle discriminating ability can be exploited in practice.

Most of the program described herein was directed at the study of the limiting characteristics of solid state detectors as described above, and, as a result of these studies, to develop optimum experiments utilizing the devices for improved measurements of the space radiation environment. This work included development of solid state circuitry appropriate to these types of experiments.

In addition to the work on semiconductor particle detection experiments, a limited amount of work was performed in an attempt to develop and perform radiation experiments utilizing nuclear emulsions and radiation sensitive mica.

II. ELECTRON AND PROTON DAMAGE EXPERIMENTS WITH LITHIUM DRIFT DETECTORS

A study was made to determine the extent of deterioration of lithium ion drift detectors due to prolonged exposure to high energy radiations. Such deterioration is relevant to use of this type of device to space probe instrumentation and in neutron spectrometers. Two experiments were performed using detectors manufactured by Solid State Radiations, Inc. The first experiment exployed 1.0 Mev electrons furnished by the General Engineering Laboratory Cockroft-Walton machine. The second experiment utilized protons from the 100 Mev cyclotron at McGill University.

The fabrication of lithium drift junctions was first described by Pell and applications of these devices to particle detection have since been described in the literature. In the particular commercial devices used in the present experiments, the depth of the depletion layer was approximately 1.5 mm.

Using an electron lens spectrometer as source, pre-irradiation measurements were made of detector response to monoenergetic electrons. A ruthenium 106 beta source, whose end point is 3.53 Mev, served as the "object" for a magnetic lens, which focussed a monoenergetic image of the source at the exit hole of the spectrometer. Using a 100-channel analyzer, detector pulse height was found to be linear with electron energy up to approximately 1.5 Mev.

For the study of damage due to 1.0 Mev electrons, the solid state detector was exposed to the electron beam through a port in a 3/8" thick aluminum plate, which protected the transistorized pulse preamplifier from radiation effects. Temperature observations showed that the temperature of the irradiation assembly rose only about $1^{\circ}C$ during the "beam on" periods.

Immediately preceding the electron irradiations, additional pre-irradiation measurements were made of detector response, using a number of energy settings of the accelerator beam (Fig. 1). In order to avoid saturation of the detector counting circuit, the beam intensity was reduced to a very low value and a .040" diameter circular aperture was placed in front of the detector. This data confirmed that obtained earlier in the lens spectrometer.

The aperture was removed, the beam current increased, and successively higher exposures were made, starting with the smallest current which could be measured in the Faraday cups. Data showed large increases in detector reverse bias current with the beam on, with rapid recovery each time the beam was turned off. After 10 and 30 minute exposure at 0.1 microamperes/cm^2, measurements were made of bias current recovery rate (Figs. 2 and 3). Recovery rates were measured at 14^{o} and $28^{o}C$, with recovery of course being more rapid at the higher temperature.

During recovery of the detector leakage current following one of the irradiations, the accelerator beam was reduced to a very low intensity at an electron energy of 800 kev and pulse height spectrum of the detector was measured.

Results were close to those obtained pre-irradiation, but an increase in noise was noted.

The total 1.0 Mev electron flux dose to the detector during the series of successive exposures was $1.6 \cdot 10^{15}$ cm^{-2} at a detector temperature of $15^{o}C$. No observable change in detector response following irradiation was seen, except for a slight increase in noise.

In order to study damage due to passage of heavier particles, an experiment was carried out using the 100 Mev proton cyclotron. Not only is the specific ionization of those particles several times larger than that of 1.0 Mev electrons, but, because of their greater mass, they are much more efficient for causing lattice displacements, which

may be expected to lead to unannealable changes in properties due to irradiation. The proton beam was kindly made available by Dr. Robert Bell, of the McGill staff.

The irradiations were carried out in a manner similar to that used for the electron irradiations. The external beam passed out of the "D" chamber through a thin diaphragm. The energy of the protons incident on the lithium drift detector was calculated as 90 Mev. The detector remained at room temperature and irradiations were carried out for successively longer periods. As in the case of the electron irradiations, large increases in leakage current were observed with "beam on", followed by rapid decay when the beam was shut down. This rapid decay was followed by a gradual, smooth decrease in current. Following a total proton dose of $3.10^{11}\,cm^{-2}$, measurement of recovery rate (Fig. 4) showed that apparently several days would be required for complete recovery. The experiment was terminated at this point.

The detector was returned to the electron lens spectrometer and pulse height spectra were taken for several energy settings of the lens (Fig. 5, 6, 7). Only a slight degradation of detector energy resolution was apparent. A small increase in noise was also noted.

Comparison of the total exposure utilized in these experiments with those expected in space probe experiments which encountered the trapped radiation belts and solar flare proton beams indicates that this type of instrumentation can survive the space radiation environment for extended periods of time if reasonable collimation is provided and if some shielding is provided against the low energy proton component. In this comparison, the electron flux in the heart of the artificial radiation belt is taken as of the order of $10^{9}\ cm^{-2}\ sec^{-1}$ and the yearly proton flux about 100 Mev is taken as being of the order of $10^{9}\,cm^{-2}$.

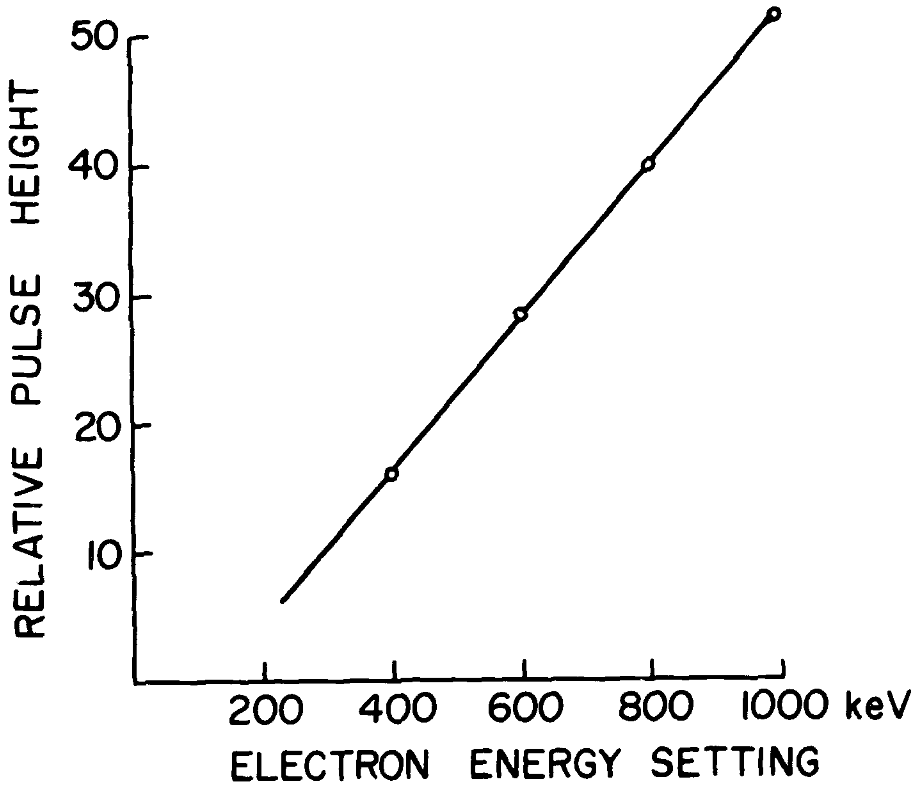


FIGURE 1. PULSE HEIGHT FROM UNDAMAGED ION DRIFT DETECTOR VERSUS ELECTRON ACCELERATOR ENERGY SETTING

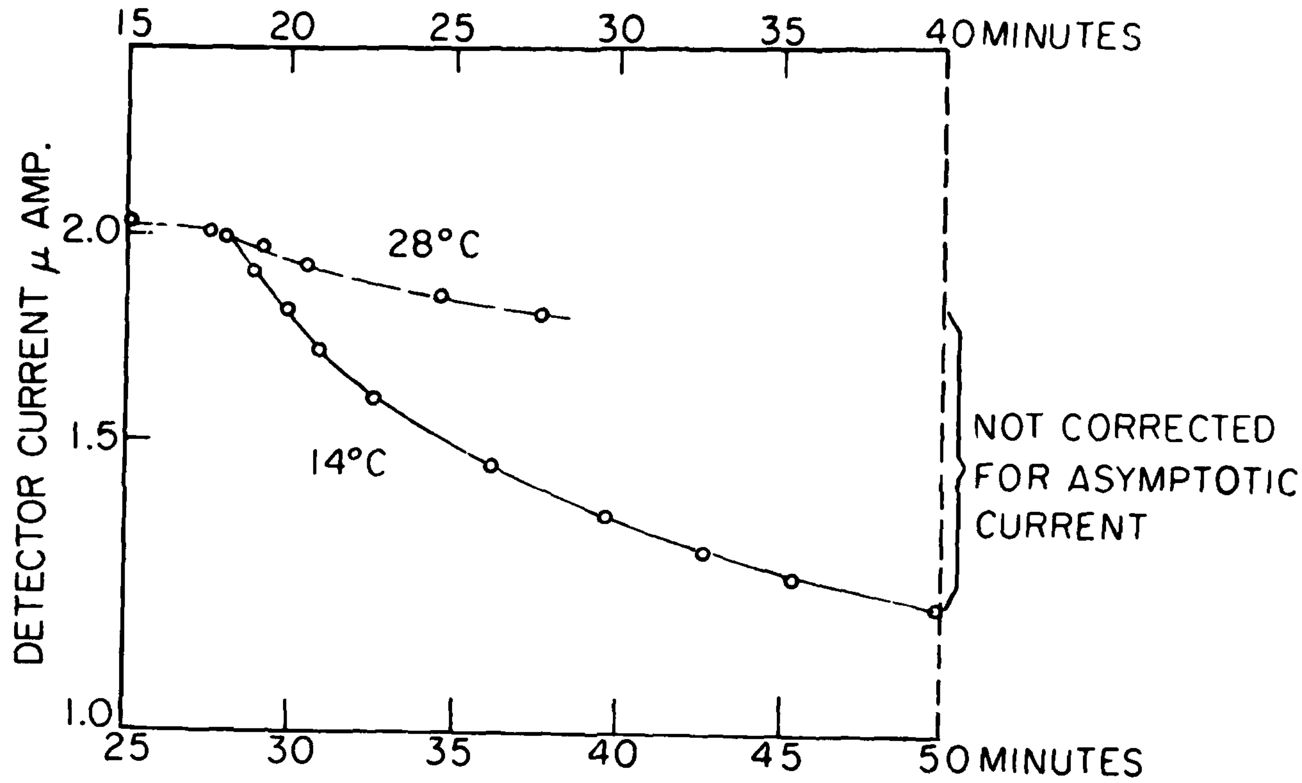


FIGURE 2. ISOTHERMAL ANNEALING OF DAMAGE FROM 10 MINUTE RUN @ .1 $\mu a/cm^2$

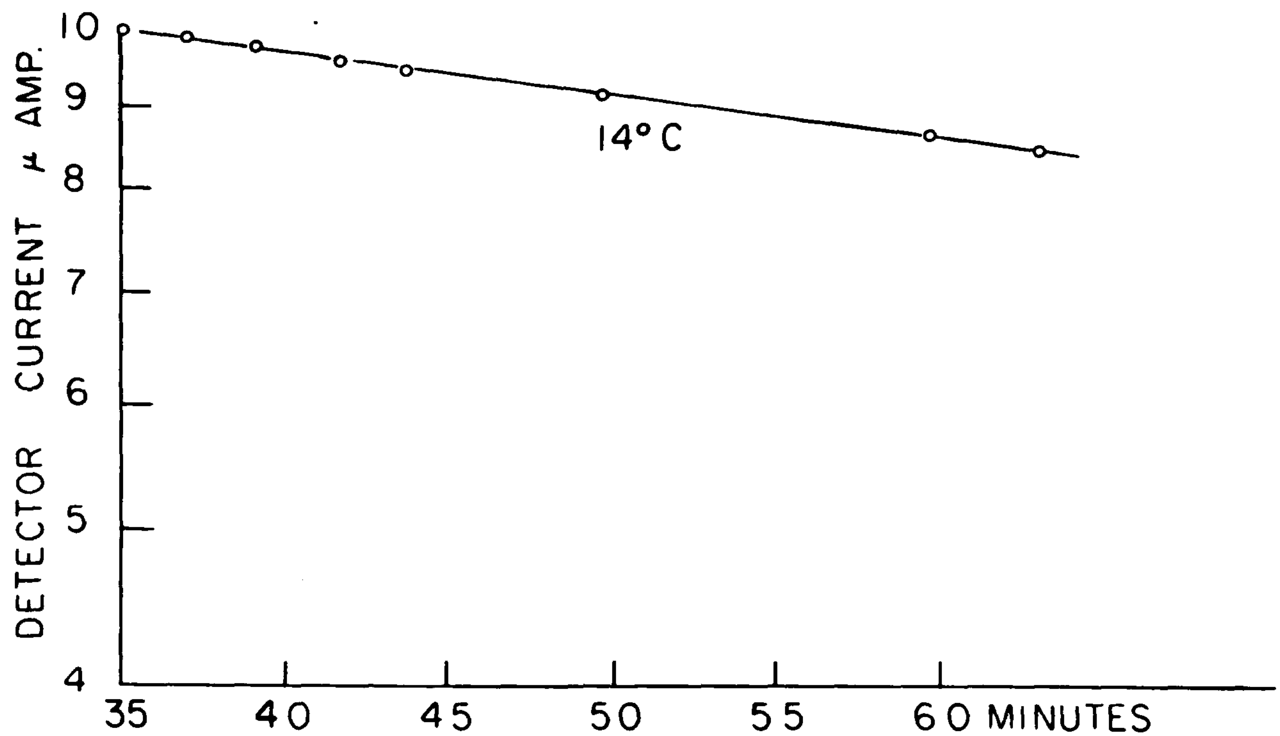


FIGURE 3. ISOTHERMAL ANNEALING OF RADIATION DAMAGE FOLLOWING 30 MIN. RUN @ .1 $\mu a/cm^2$

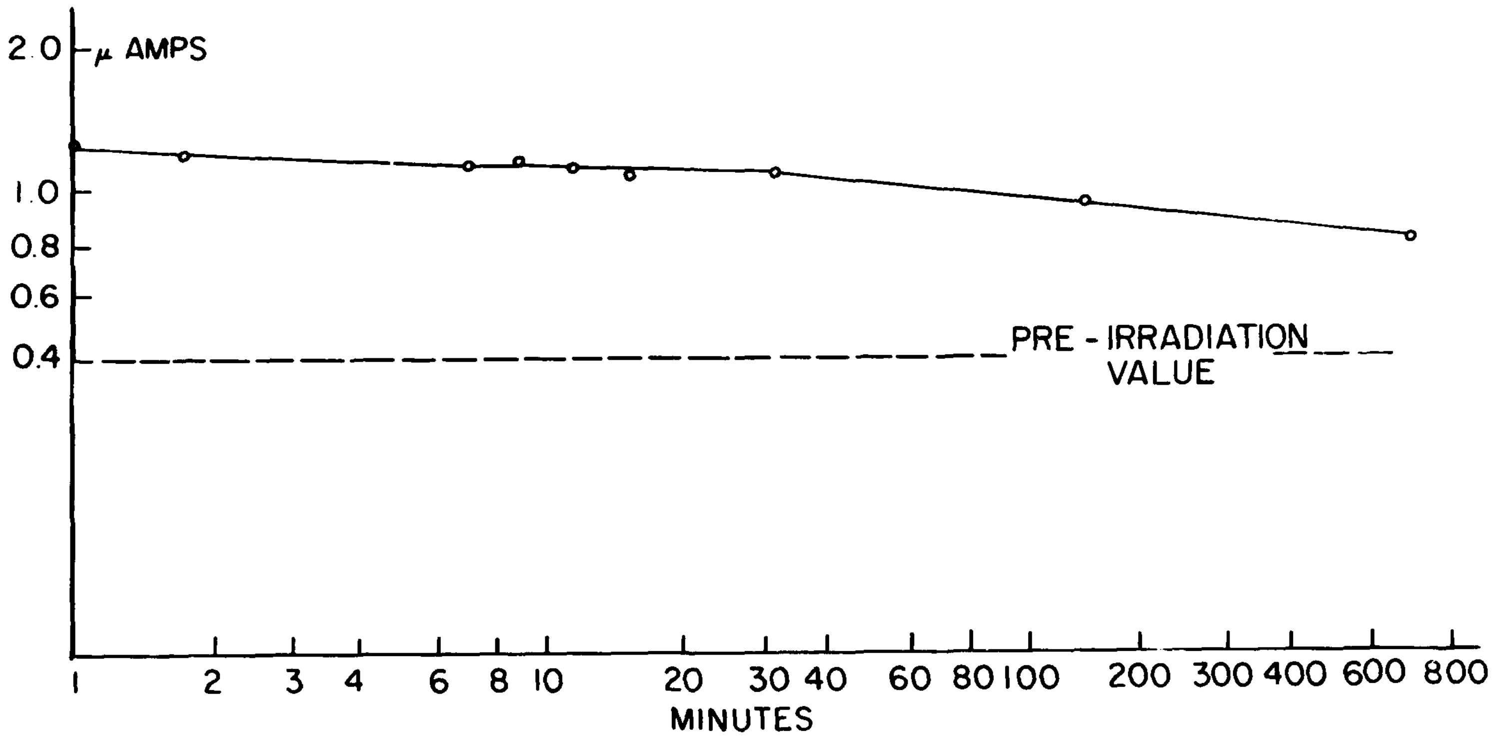


FIGURE 4. DETECTOR LEAKAGE CURRENT FOLLOWING TERMINATION OF PROTON BOMBARDMENT

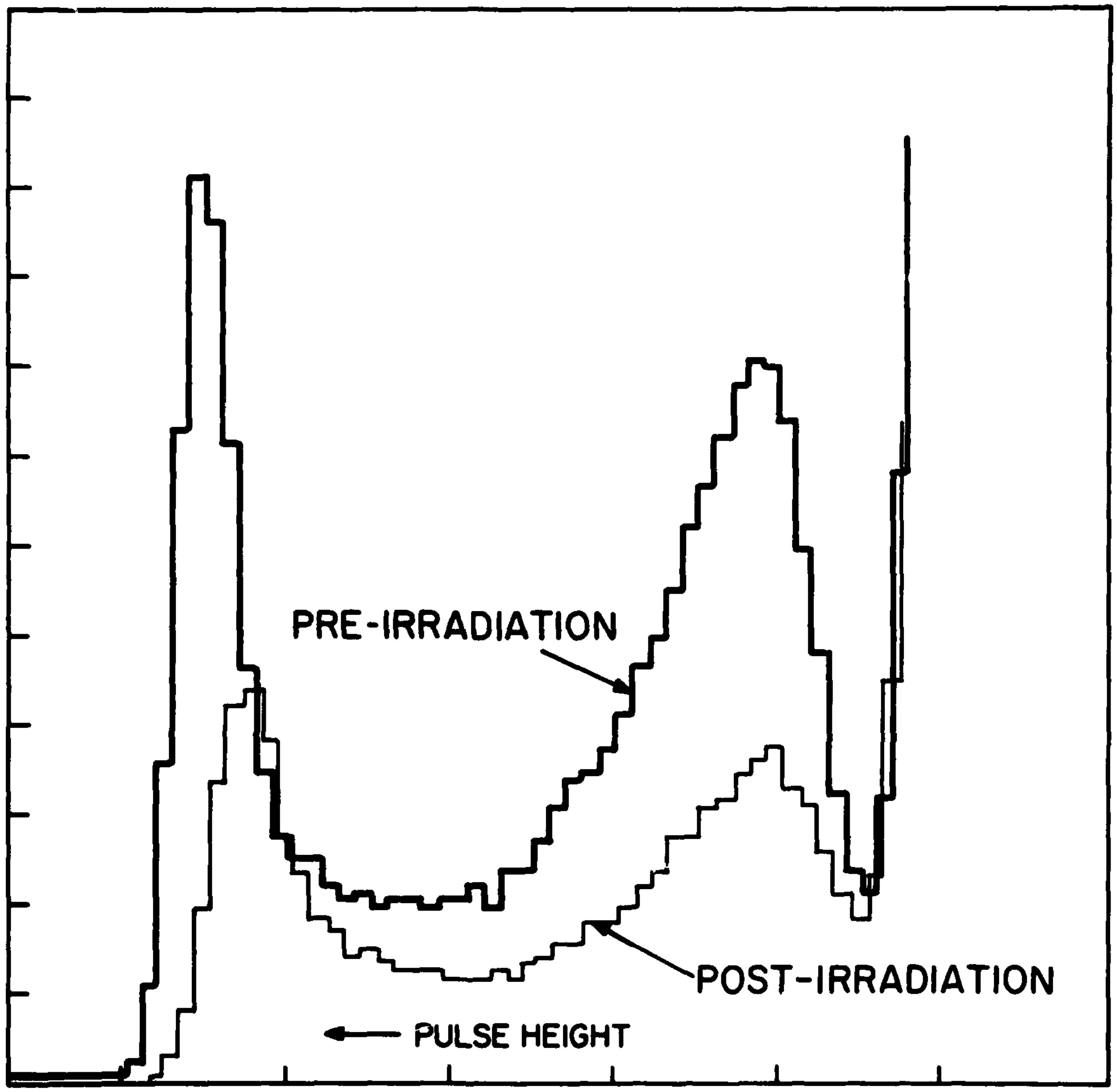


FIGURE 5. DETECTOR RESPONSE TO 1.05 Mev ELECTRONS

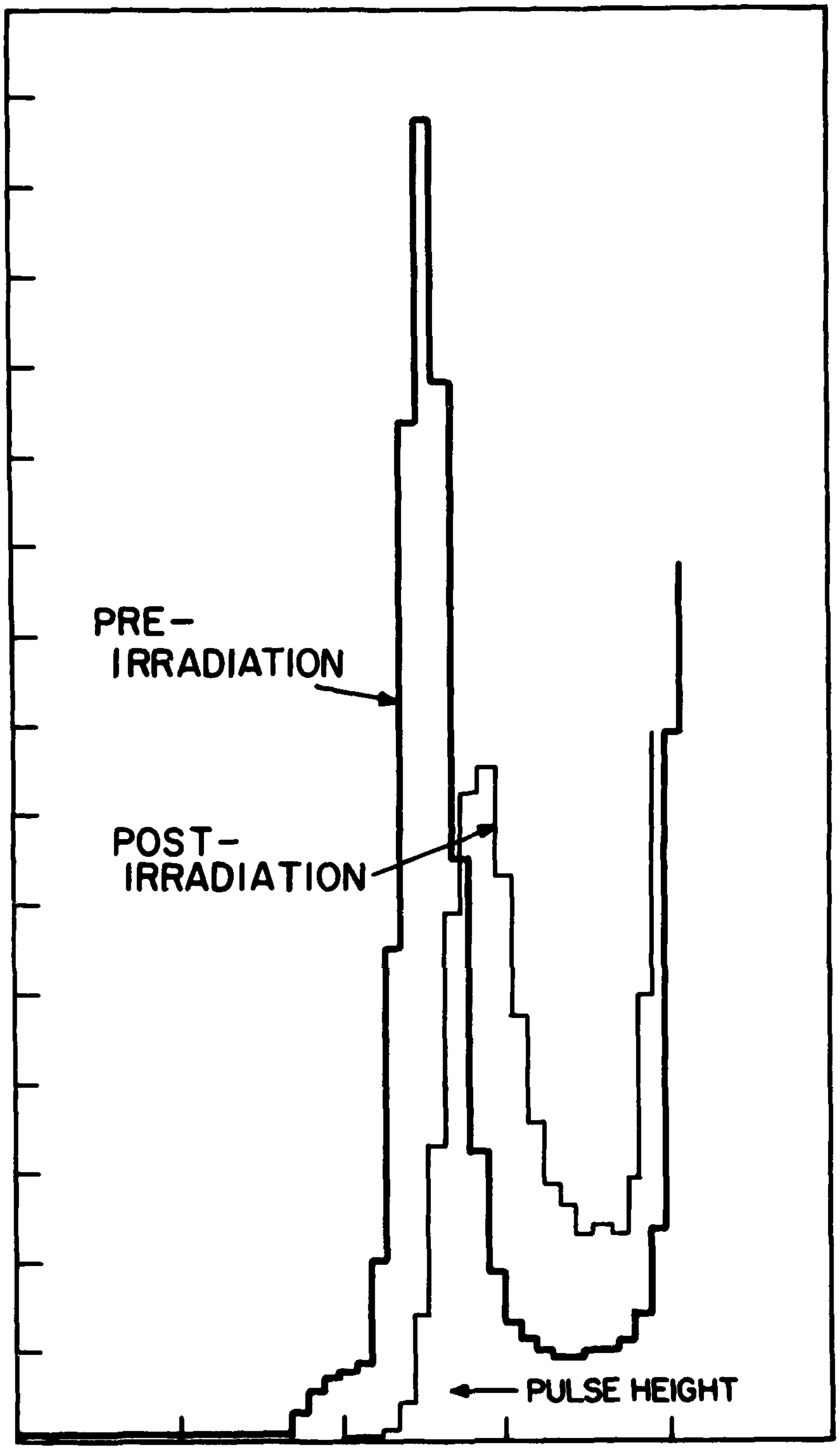


FIGURE 6. DETECTOR RESPONSE TO 600 Kev ELECTRONS

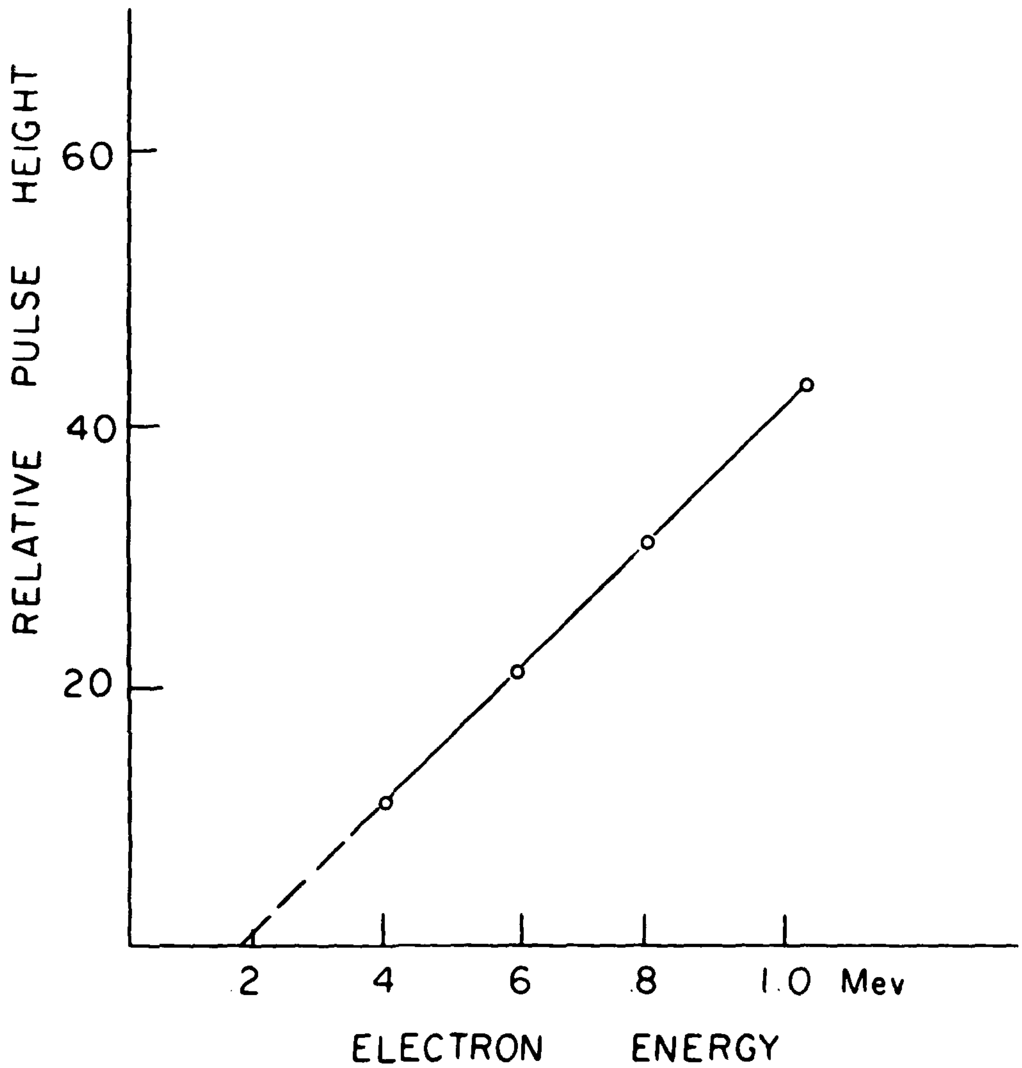


FIGURE 7. POST-IRRADIATION DETECTOR RESPONSE

III. ELECTRON TELESCOPE DEVELOPMENT

Before the advent of high altitude nuclear testing, some information was becoming available regarding the nature and spectrum of the geomagnetically trapped radiation at low altitudes. For example, it had been concluded that, at 1000 km altitude, the radiation intensity (302 Geiger tube count rate) behind light shielding was primarily due to penetrating electrons for $L > 2.2$, due partially to electrons and protons for L in the range $1.8 < L < 2.2$, and primarily due to penetrating protons for $L < 1.8$. The situation has been of course considerably complicated as a result of U.S. and Soviet high altitude nuclear testing. Much of the data obtained since the creation of the artificial electron belts has been complicated by bremsstrahlung due to stopping of high energy electrons in the walls of the instruments or flight vehicle. This has been particularly true for magnetic electron spectrometers which have relatively narrow acceptance angles. For this reason it was decided to develop an operating breadboard model of an electron telescope as part of the IRP program. This objective was met in 1962 and a proposal for outside funding was submitted to prepare and fly an electron telescope based on the breadboard design. Further, such an instrument can easily be adapted to a proton telescope by simply raising the threshold for pulse acceptance.

Description of Instrument

A two-channel electron telescope is depicted schematically in the block diagram of Figure 8. A "dE/dx" detector of 0.1 gm/cm^2 thickness is followed closely by two lithium drift detectors of thickness 0.45 gm/cm^2. Pulses from the detectors are amplified and fed to coincidence circuits. Starting with the dE/dx detector, the detectors and preamplifiers are numbered 1, 2, 3. A 1-2 coincidence corresponds to the passage of an electron sufficiently energetic to penetrate detector 1 and give a pulse in detector 2 above the bias level. This bias would be set to detect electrons having an initial energy greater than about 600 kev. A small

amount of stopping material (about .5 gm/cm^2) would be added between detectors 2 and 3 and the bias of detector 3 would be set so that a 1-3 coincidence would correspond to passage of an electron of energy greater than about 2 Mev. The coincidence rates would be recorded and/or telemetered to give a measure of the integral electron flux above .6 and above 2 Mev. The 2 - 3 coincidence rate gives a redundancy which would still yield coincidence data in the event of failure of any one of the detectors, preamplifiers, or data channels. The singles counting rates of detectors 1, 2 and 3 are telemetered in order to allow calculation of accidential coincidence rate. The singles rate of detector 1 also gives data on the omnidirectional radiation intensity. Since the efficiency of the thin detector is low for bremsstrahlung but nearly unit for minimum ionizing electrons, the counting rate of detector 1 would give a high amount of discrimination against bremsstrahlung. The singles rate of detectors 2 and 3 will contain a considerable contribution from bremsstrahlung. This data could be compared to Geiger tube count rate data behind similar thickness of shielding material.

Detectors and Pulse Amplifiers

Channel No. 1

Solid state devices for energetic charged particle detection are available from a number of sources. dE/dx detectors presently available from Molchem Corporation of Princeton, New Jersey, were elected for use in the developmental telescope. A proprietary development by this company allows complete depletion of a 0.1 gm/cm^2 silicon wafer with the application of only 30 volts of bias. Experimental comparison of such a device with others obtainable at the time showed a definite superiority for detection of minimum ionizing electrons in terms of signal to noise ratio. Figure 9 shows pulses obtained from minimum ionizing (1.5 Mev) electrons. The data was obtained using monoenergetic electrons from the electron lens spectrometer shown in Figure 10. Figure 9 was obtained by photographing the display of a 400 channel pulse height analyzer. The

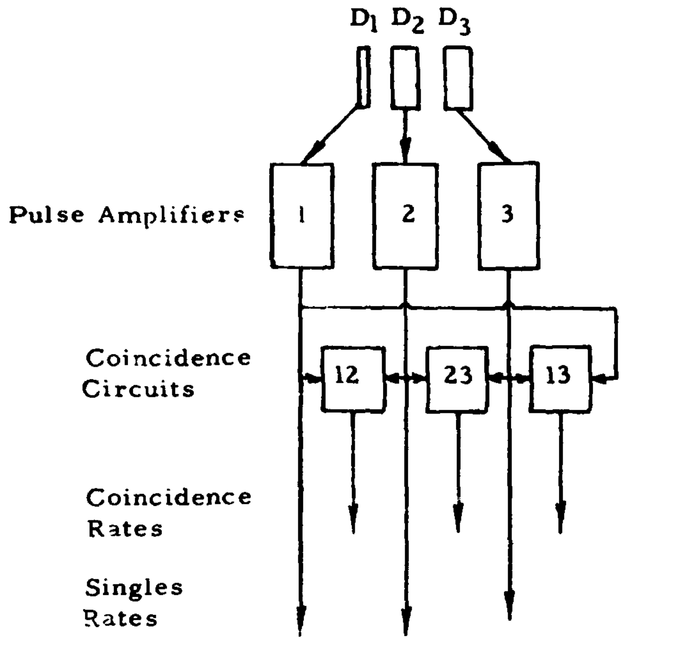


Fig. 8

Two Channel Electron Spectrometer
Block Diagram

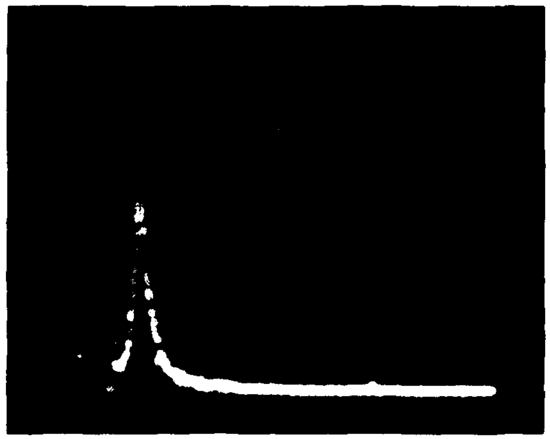


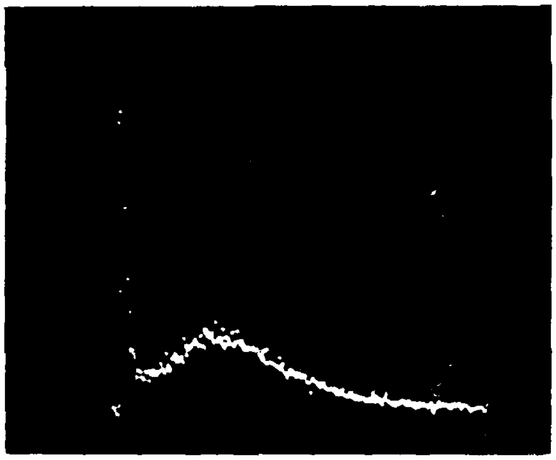
Fig. 9 Pulse Height Spectrum from Minimum Ionizing Electrons 0.1 gm/cm^2 dE/dx Detector.

Fig. 10 MSD Electron Lens Spectrometer

pulses were amplified in a low noise laboratory-type pulse amplifier. Low noise preamplifiers of this type have inherently long pulse decay times, which limits their usefulness in satellite experiments where extremely high count rates can be encountered. Figure 11 shows pulses obtained from minimum ionizing electrons after amplification in a developmental circuit such as that shown in Figure 12. This circuit, utilizing special transistors, was found to be a compromise in which reasonably low noise level could be achieved with an output pulse length of only 3μ sec. achieved by clipping. It is recommended that this amplifier be adopted for the flight instrument, since it is simple and rugged. The electron count rate corresponding to Figure 11 was only about 50/sec., and even for this low count rate the noise contribution above the bias suggested is not excessive. Noise pulses will in any event be discriminated by the operation of the coincidence circuit. In the more intense regions of the trapped radiation belt, the contribution of noise pulses to even the singles counting rate in channel 1 will be negligible.

<u>Channels No. 2 and 3</u>

The problems associated with the channels utilizing the lithium drift detectors are considerably simpler because of the larger pulse obtainable from the thick sensitive regions of these detectors. The problem of preamplifier noise is not critical in any channel utilizing the lithium drift detectors, as it is in the dE/dx channel. For the sake of uniformity, however, the same type preamplifier would be used in these channels as in the dE/dx channel (#1), except that less amplification would be provided.



Suggested Bias

Fig. 11 Pulse Height Spectrum of Minimum Ionizing Electrons (~50/sec) Plus Noise - 0.1 gm/cm^2 dE/dx Detector

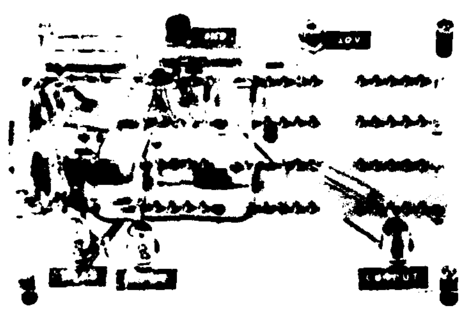


Fig. 12 Pulse Preamplifier Developed as Breadboard for Flight Equipment

Coincidence Circuits

Coincidence circuits have been built in this laboratory utilizing tunnel diodes which have been tested to have resolution far in excess of that required for the proposed application. Even simpler diode coincidence circuits would be used for the present application. Pulse threshold discrimination can be provided by this circuit. Pulse clipping would be utilized in the final stage of the pulse amplifier.

Data Conditioning Circuits

The data conditioning circuit recommended for this experiment is shown in Figure 13 and is a modification of a circuit developed by Dr. G. L. Miller of the Brookhaven National Laboratory. This circuit is a logarithmic count rate meter which can cover the range from 1 count per second to 1.5×10^5 counts per second. The output of the circuit is a DC voltage varying from 0 to 5 volts, where each volt corresponds roughly to a decade. By adjusting the values of the R's and C's, it is possible to change the correspondence between the count rate and the 0 to 5 volt output signal.

The coincidence channels would be provided with log count meters capable of handling rates from approximately 15,000/sec down to single counts. The limitation on the high end arises because the coincidence rate will be an order-of magnitude lower than the singles rate of the dE/dx detector. Above this rate, the accidental rate will rise sharply and saturation of the singles channels will make an accurate singles rate unavailable for calculation of the accidental rate. On the low end, even individual events are expected to be significant because of the discrimination against noise provided by the coincidence arrangement. Data rates down to approximately 1 C/sec can be handled by this particular circuit so that the usefulness of the data at extremely low count rates would be limited only by excessive vehicle motion between counts.

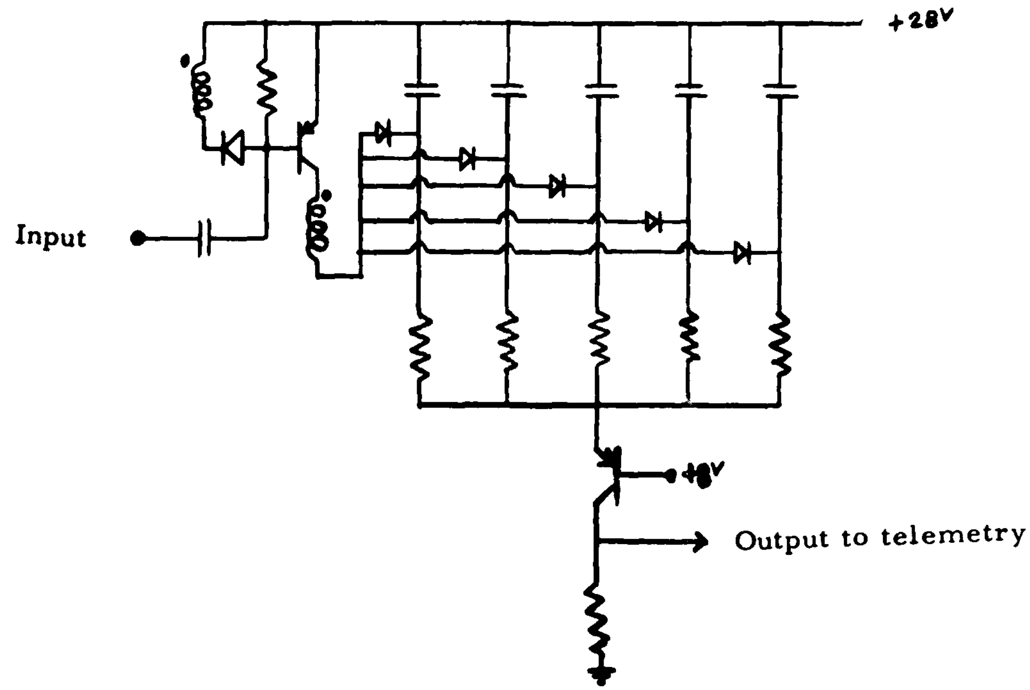


FIGURE 13. LOG COUNT RATE METER

Present Status of Electron Telescope Development

By the end of 1962 breadboard models of all of the components of an electron telescope had been built and tested. In addition, the separate components of the telescope were integrated and an operational breadboard electron telescope assembled. The telescope was tested and it demonstrated the ability to detect minimum ionizing electrons.

It is hoped that in 1963 Space Sciences Laboratory funding can be made available to built a flight model of this telescope and that an experiment can be performed utilizing this telescope.

IV. EMULSION EXPERIMENT

An inexpensive space experiment was planned using film badges and nuclear emulsions. This experiment was prepared to be flown in the latter part of 1962, however vehicle difficulties prevented successful completion of the experiment. This program was carried out jointly by the following operations: Materials Studies, Aerophysics, and Electron Physics. Similar experiments are being prepared for flight during 1963. These experiments have the advantage that they are very light weight, compact and completely passive, i.e., they require no power.

These experiments, if flown, would yield significant flux and spectrum data on the fission spectrum electrons trapped in the artificial radiation belts. Such experiments are of value in that the flux and spectrum of these artificial belts are continually changing, and by frequently monitoring these changes we can evolve a better theoretical understanding of the mechanisms at work in the geomagnetic field.

V. MICA EXPERIMENT

The possibility of using mica as a heavy ion detector has been explored. It is known that fission fission fragments leave permanent tracks in mica crystals, while alpha particles and protons do not, unless they produce recoil nuclei in the crystal. Thus, mica seems attractive as a means of detecting rare heavy trapped nuclei in the earth's radiation

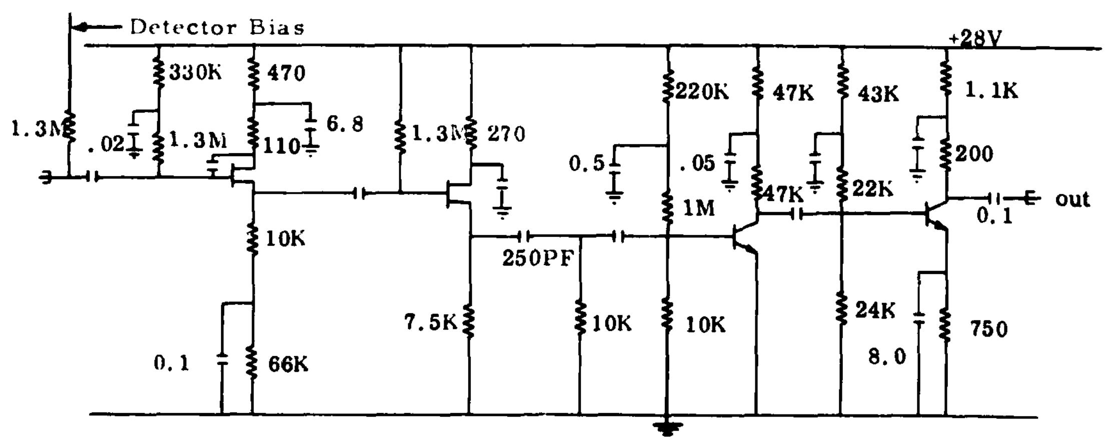
belts amidst intense fluxes of lighter particles. However, it was not known just what the nature of the incident radiation must be to leave tracks in the crystal.

In order to help resolve this question, mica was exposed to nitrogen ions accelerated to energies between 0.1 Mev and 1.0 Mev. The result was that no tracks were produced. Later work performed at the GE Research Lab indicated mica is completely insensitive to particles with a rate of energy loss less than about that of a 150 Mev Argon-40 nucleus.

Because such heavy particles are required for track production, the mica is less attractive for space applications than if it were sensitive to nitrogen and oxygen nuclei. However, there is an outside chance that heavier particles may be geomagnetically trapped. Plans are being made to fly mica aboard a re-entry vehicle in 1963.

VI. PREAMPLIFIER DEVELOPMENT

The following sketch shows a preamplifier circuit designed with the use of field effect transistors. The preamplifier had a noise level of 8 Kev for the best commercially available transistor preamplifiers and 5 Kev for the best commercial tube preamplifiers. This preamplifier suffers from being voltage sensitive rather than charge sensitive; attempts to introduce feedback to make it charge sensitive resulted in oscillations. Nevertheless, the value of field effect transistors for low noise amplifiers was demonstrated.



VII. CONTOURED DETECTORS

In a joint effort with another IRP program, a study of semiconductor detectors with beveled edges was begun. It was shown that the noise level does not change much from low voltages to 80% of breakdown.

In one case, internal multiplication of some of the pulses was found. Alpha pulses were occasionally increased by a factor of 4. Electron pulses were multiplied by factors up to somewhere between 35 and 140. Most of the particle pulses were not multiplied. The electron multiplication disappeared after the destruction of a forward biased surface barrier junction on one surface.

The explanation of the multiplication effect is uncertain. Several possibilities are advanced:

(1) induced avalanche in the bulk of the crystal

(2) transistor action due to a charge imbalance in the space charge region

(3) a distortion of the barrier with a higher local field and, hence, increased current.

(4) increased diffusion current due to space charge effects near the surface barrier

Study of this effect is continuing.